Models and Tools for Acquisition Knowledge Management

Final Report

Funded by the External Acquisition Research Program, Naval Postgraduate School,
Contract N00244-00-C-0094

August 27, 2001

Balasubramaniam Ramesh
Department of Computer Information Systems
Georgia State University
35 Broad Street, Atlanta, GA 30303

Abstract

We view the acquisition of complex systems, products and services a knowledge intensive collaborative activity. We identify problems associated with knowledge management in the context of complex acquisition activities involving cross functional collaborative teams. We map these problems to the characteristics for a knowledge management system to support acquisition activities. We have developed a prototype knowledge management systems to support complex acquisition activities such as the development of information products. The system can be used to capture and manage tacit and explicit process knowledge involved in complex acquisition activities.

1. Knowledge Management in Acquisition

1.1 Introduction

As we move further into the information age, knowledge is becoming a critical component of competitive success of organizations [22]. Nonaka [50] observers that as markets shift, technologies proliferate, competitors multiply and products become obsolete rapidly, successful organizations are characterized by their ability to consistently create new knowledge, quickly disseminate it and embody it in their activities. Such knowledge utilization is innately a collaborative process [1]. Collaboration refers to informal cooperative relationships that build a shared vision and understanding. The proposed project views Acquisition (of especially, complex systems, products and services) as a collaborative, knowledge intensive activity and proposes the development of models and tools for knowledge management to support acquisition activities.

Specifically, this project addresses the problems faced in the retention and maintenance of **process knowledge** that is created in complex acquisition activities such as the acquisition of a complex computer based system. We define process knowledge as tacit and explicit knowledge about activities, steps and procedures. It is based on the premise that current acquisition methodologies do not adequately address the capture and use of this knowledge. As much of the formal and informal knowledge along with the context associated with it, is lost after the process is completed, acquisition teams are unable to leverage knowledge actualized by earlier teams. We propose the creation and use of a repository of information and knowledge derived from sources such as recorded decisions, text documents, images, audio and video, specifically relating to collaboration within teams.

The discussion is structured as follows:

- Definition of knowledge and identification of the various types of knowledge involved in an acquisition process.
- Role of Knowledge Management Systems
- Role of acquisition as a knowledge intensive activity
- Knowledge Management in Acquisition with emphasis on
- Need for Managing Knowledge in Acquisition
- Characteristics of complex Acquisition Processes
- Problems in complex Acquisition Processes

The above discussion is used to elaborate on the two important components of the current project.

First, this project seeks to develop a c mprehensive set of requirements for an Acquisition Knowledge Management System (AKMS). We discuss in detail some initial requirements based on the survey of current literature. The proposed project will evaluate and refine these initial requirements.

Second, this project will include the development of a prototype AKMS. The functionalities of such a system must be based on the requirements identified above. Based on the review of related work, this project provides a preliminary assessment of the functionalities of the AKMS. These will be evaluated and refined in the current project. We have identified the development complex information products as the acquisition activity within which the concepts discussed in this first chapter will be explored further. Specifically, the functionalities of the AKMS will be discussed in the context of acquisition of complex information products.

1.2 Background

1.2.1 Towards a Definition and Understanding of Knowledge

Davenport and Prusak [20] suggest that knowledge originates and is applied only in the mind of knowers (holders of tacit knowledge) and in organizations it is embodied in documents, repositories, organizational routines, processes, practices and norms. Several researchers [18, 20, 50], define tacit knowledge as personal, context specific knowledge that is difficult to formalize, record or articulate or encode. Explicit knowledge on the other hand, can be codified and transmitted in a systematic and formal representation or language. Nona and Takeuchi [52] reduce knowledge creation to conversion of tacit knowledge to explicit knowledge. Rug [59] suggests that knowledge management creates value by actively leveraging the know-how, experience and judgment resident within and outside an organization. We posit that knowledge management encompasses the activities surrounding the integration of this knowledge from different sources and in different forms and maintaining it. The key to knowledge creation thus lies in mobilization and conversion of this tacit knowledge into a form of explicit knowledge. Davenport and Prusak [20] indicate that some knowledge is complex and initially tacit, but can, however, be externalized and embedded in an organization's products and processes.

1.2.2 The Role of Knowledge Management Systems

The development of systems to assist in managing knowledge has been a topic of considerable interest [51]. Nonaka and Konno [51] suggest information systems can assist knowledge activists (proponents and champions of KM systems) to serve as catalysts of knowledge creation and as *connectors* of present initiatives with those in the future. Tiegland et al. [69] observe that facilities to capture, reuse, maintenance and transfer of knowledge are essential elements of such a system. They suggest that such a channel for supporting the demand for knowledge within an organization will be very valuable [69]. To transfer tacit knowledge from individuals to a repository, Davenport et. al. [18] suggest support for some form of community based electronic discussion. A key feature that would differentiate a knowledge management support tool from a project management tool or organizational memory store is the ability to capture and retrieve uncodified or tacit knowledge.

1.2.3 Acquisition as a Knowledge Intensive Activity

Eder [24] suggests that much of the knowledge in complex activities (such as acquisition of a complex system involving knowledge about the strategic design approach and knowledge about tactics and methods for designing) is tacit. Acquisition often involves cross-functional linkages, where different participants join a team with differing viewpoints. Such teams are often characterized by participants who achieve a high level of at-stakeness and synergy from their interaction [36] with other team members. Morrison [47] suggests that this interaction brings in a need to organize, integrate, filter, condense and annotate [46] collaborative data and other relevant information that these team members contribute. Since a substantial portion of this knowledge is tacit, we focus on the development of knowledge management tools to support the creation of internal, informal knowledge repositories containing such knowledge.

1.2.4 Knowledge Management in Acquisition

Collaboration is the centerpiece of complex acquisition processes. It is essential to distinguish between collaboration and interaction for the purpose of distinguishing knowledge involved in the two processes. Collaboration is imperative in knowledge generation and transfer [59]. While interaction refers to formal, transactional communication links, collaboration refers to informal, cooperative relationships that build a shared vision and shared understanding needed for conceptualizing cross functional linkages in new product development contexts [36].

In a well managed development process, a cacophony of perspectives foster creative abrasion, which Leonard-Barton and Sensiper [42] define as an intellectual conflict between diverse viewpoints that produces energy channeled into new ideas and products. We observe that to enable a high degree of cross-functional collaboration, supporting the development of a shared vision and understanding is crucial. According to Ruggles [59], managing knowledge in collaborative teams allows cross-fertilization among sources of internal expertise and creates networks of knowledge workers within and outside the organization.

Need for Managing Knowledge in Acquisition

Davenport [20] suggests that innovation and speed to market that are essential for business success will become increasingly critical in the future. According to Quinn [54] the intangibles that add most value to these activities are knowledge centric. Consider for example, the acquisition of a complex software system. Most such activities are moving towards team based structures, since teams are believed to increase individual commitment and performance and as Galegher [29] observes, are more effective in bringing a product to the market in a shortened time frame. As products and technologies become increasingly complex acquisition requires the collaboration and skills of several individuals.

Characteristics of complex Acquisition Processes

A review of literature suggests that collaborative activities such as complex systems acquisition has several key characteristics that result in a variety of knowledge management problems.

- *Short product and process lifecycles* : Bettis [6] observes that product lifecycles (especially, with computer based systems) have significantly shortened thereby compressing the available time window for recouping the expenses associated with product development [6].
- *Cross functional collaboration*: In order to respond to competitive challenges, organizational units have become more closely coupled than in the past, often working in parallel to complete assignments spanning traditional units [29] and functional areas. Leonard-Barton [42] suggests that creation of today's complex systems of products requires merging of knowledge from diverse disciplinary and personal skills-based perspectives where creative cooperation is critical for innovation
- *Cross-institutional collaboration:* Besides spanning multiple functional areas within an organization, development of complex products also requires bringing together participants from across

multiple collaborating organizations [1]. Expertise and skills might be distributed both within and outside the developing organization [35]. Davenport [20] suggests that this brings in the need to facilitate knowledge growth knowledge sharing and dissemination.

- *Transient existence of teams and high turnover*: In large projects, membership in development teams changes over time and across phases. A major threat to the collective knowledge in organizations is personnel turnover, since much of this knowledge is situated in the minds of individuals [66]. Carley [10] observes that when there is no repository for knowledge other than personnel, turnover leads to reduction in the organizational knowledge. Similarly, March [44] observes growth of organizational code under conditions of low turnover and high socializationProblems in complex Acquisition Processes

The above characteristics of complex acquisition lead to a variety of problems that suggest the need for better knowledge management.

- *Lack of shared understanding:* Uncertainties in development processes lead to dependencies among and between different functional areas and require cooperation to accomplish individual and joint objectives [64]. Szulanski [67] conjectures that the consequences of this problem are the lack of absorptive capacity of the recipient, and the inability to contextually understand best practices in development.
- *Over reliance on transmitting explicit rather than tacit design information* [20, 21, 25, 52]. Nonaka and Takeuchi [52] have pointed out the importance and value of recognizing and capturing tacit information – such as know-how, judgment and intuition, which make up a critical component of information that needs to flow between members collaborating within a team. This highlights the need for a method to effectively transfer such knowledge in addition to explicit knowledge.
- *Repeated mistakes*: Organizations have been frustrated by reinventing solutions and repeating mistakes due to their inability to identify or transfer lessons learned from failures from one location to another or one function to another (Dell,1998). Transfer of knowledge from failed projects to new ones could substantially reduce the expenditure of resources and effort. Teece

(1998) suggests that innovations in complex systems development involve a considerable degree of uncertainty and that knowledge about failed approaches is frequently forgotten, resulting in their repetition..

- *Reinvention of solutions* during product evolution: Another problem in complex system acquisition teams is that they expend resources into solving problems that might have already been solved either within or outside the collaborative group. Based on empirical observations in software development, Ramesh and Sengupta [56] conclude that work groups often repeatedly discuss the same issues that had been resolved earlier, as there may exist no reliable record of these.

  Teece [68] indicates that the annual aggregate 'reinvention' costs in the United States range between $2 billion and $100 billion. Court [15] offers support for the suggestion that product designers often tend to use the incomplete information they already possess, rather than seek expertise that does exist within the enterprise and external to it.

- *Skills developed due to collaboration may be lost thereafter* Quinn et. al. [54] suggest that professional know how is developed most rapidly through repeated exposure to the complexity of real problems. In a project oriented team-based organizational structure, skills developed during the collaboration process might be lost after the team is broken up and redistributed [56] amongst other teams or groups working on newer development projects. When a team is disbanded, the process knowledge acquired by the team is lost and is not available for tasks such as product modification or maintenance [32].

  Ad-hoc teams formed for complex system development are often disbanded at the end of the development. Team members often get assigned to other projects wherein their functional expertise is more valued than their knowledge gained during their collaboration with other functional and technical areas.

- *Inability to transfer existing knowledge into other parts of the organization* [59]: Many organizations face difficulties in transferring knowledge from one part to another. Gallagher et al [29] highlight the problem in the diffusion phase wherein team members begin transferring technical data as well as a sense of ownership to other groups that must manufacture and market the new product. Maintaining motivation for knowledge transfer at this stage is challenging as all major product development decisions have already been made and what remains is the completion of product details.

- *Inconsistency in multiple versions of information:* Recent research (such as [3, 4, 9, 15]) suggests that an enabling condition for knowledge creation is redundancy. Redundancy offers an overlap in knowledge between different groups that promotes cross-functional collaboration. The need for redundancy, however, needs to be met simultaneously with the need for maintaining consistency across different versions of information that may be possessed by different team members.
- *Evolving assumptions* Design decisions made in the process of developing a new product might be based on some critical assumptions [8], both technical and non-technical. Due to the dynamic nature of product development activities these assumptions often change [55], necessitating reevaluation of the decisions that depend on them
- *Loss of tacit knowledge* [59] tacit knowledge is difficult to articulate in a way that is meaningful and complete, it is often lost [68]. Teece [68] suggests that the larger the extent to which a unit of knowledge has been codified, the lower are its transfer costs. Uncodified or tacit knowledge is not only slow to transfer, but also leads to ambiguities [68].

1.3 Our Approach

1.3.1 Initial Requirements for a Knowledge Management System

The focus of our research is the development of a knowledge management system to support collaborative acquisition activities. As a first step, we identify the requirements for such a system by examining the various knowledge management problems faced by the acquisition process. We then identify general solutions to these problems suggested in the literature. Finally, we identify specific requirements for a knowledge management system based on these general solution strategies. We present the above analysis in Table 1. Here, specific system requirements have been denoted by functionality codes (within {parenthesis}). These requirements are elaborated in the next section.

Table 1: Mapping problems to system requirements to support process knowledge management

Problem faced by acquisition process	General solution	System requirements
Over reliance on transmitting explicit rather than tacit knowledge [18, 33, 42, 51]	Convert a part of tacit design knowledge into explicit, by recording assumptions and beliefs [25] [26] [50].	Multimedia capabilities integration {MM} that forces users to think through the process by articulating dependencies on cross functionally significant aspects of the design [4, 5, 30] . Integration with underlying assumptions {IA} [56]. This would allow for the creation of a strategic agreement between the various participants.
		Multimedia support to capture knowledge that can not be explicitly codified {IK}. This would facilitate knowledge transfer and exchange [49, 56]. Support for recording assumptions {RA} and recording beliefs {RB} [55].
Barrier due to lack of absorptive capacity [65, 70].	Retain context along with information stored.	The context of each decision [18, 20] in the process can be captured with each concept {DC}.
Changing team membership [18, 20, 31] Repeated mistakes [68]; Reinvention of solutions [68].	Divorce knowledge from the holder, convert to explicit knowledge	Each team member's augmentation to the design discussion process is captured in the deliberation records {DR}.
	Capture past design experiences in a manner useful for later reference during design processes.	Design information from past projects {DP} and current projects {DN} is accessible to the present team. Such information is available both for past and ongoing projects throughout the enterprise by means of a distributed workspace enabled by a communications network {NE}.
	Create well indexed knowledge of similar problems faced in earlier groups and teams.	Design knowledge - both formal and a part of the informal - from past projects {DP} {DN} is readily available and captured within the system. Ad-hoc retrieval of informal information is supported using meta tags.
Shared medium	Shared medium between cross cultural team members provides a common discussion field.	Shared medium {SM}; consistently interpretable (across functional and national boundaries) forms of representation using icons {GI} ; retention of credit to the original contributor (for contribution credit and reward matching), are supported by the system {AT}
Loss of collaborative skills [54, 60, 61].	Support capture and reuse of knowledge created during the collaborative process itself.	Collaborative design dialog {CD} throughout the design process is captured as a process. Such a process can be replayed or reenacted to reveal the sequential and parallel activities and contexts of past design decisions {RE}.
Versioning of information [59, 60].	Store multiple and identifiable versions of content at a single central remotely accessible repository.	Versioning of process knowledge is supported by the system {VC} [51, 52, 76].
Process knowledge might be lost after the project is completed	Retain dialog between the members of the design team as a part of captured knowledge [26].	Preserve antecedent dialog between the members of the design team as a part of captured knowledge {DR}.

[32].		
High Development costs [14]	Reuse knowledge, processes and design artifacts from past projects.	Decisions from both the current and past projects are available {DP} {DN} {NE}. This can potentially reduce the time spent in reinventing solutions and the costs incurred in the process [20, 23].
Unstated assumptions [55, 56]	Record assumptions made in the design process.	Each decision made in the design process can based on multiple assumptions which are linked {LA} to it [25]. Monitor the ramifications of any changes.

1.3.2 Preliminary Assessment of AKMS Functionalities

The development of models and tools to support knowledge management tasks in collaborative acquisition activities is the focus of our work. In this section, we provide a preliminary assessment of the functionalities that an Acquisition Knowledge Management System should posses. The functionalities of the proposed tools are grounded in the "requirements" identified in Table 1. A primary outcome of the proposed project is the evaluation, modification and refinement of these preliminary assessments and the development of a prototype system that provides these functionalities.

Definition of Concept Maps

As a first step in supporting the capture and use of process knowledge for acquisition involves the identification of the critical components of knowledge. Our prototype system should provide the ability to define meta models in terms of objects representing knowledge components of interest. Further, associations among these components can also be represented. Finally, characteristics or attributes of concepts can also be easily specified. Once a meta model (or a schema) is defined, users of the system can instantiate these models. Ramesh and Sengupta [35] describe a candidate meta-model which was derived from our earlier work on new product development activities. In this model, concepts are knowledge components that can be used to represent the participant's views of interests, concerns and tasks [40]. A concept may suggest other concepts, elaborate on others, and even depend on others. A few specializations of concepts were also identified. These include issues, alternatives, justifications and assumptions. Issues are questions or concerns that need to be resolved to arrive at decisions, and alternatives are various answers or solutions to these issues. Justifications that are for or against these alternatives are also included in the model. Finally, assumptions underlying concepts are also represented. This model is similar to the Issue Based Information Systems (IBIS) model of argumentation [13] that has been used successfully in a wide range of domains to represent complex problem solving processes. It should be noted that the choice of the specific meta model is entirely up to the users of the tool. The system should support the definition and instantiation of any model chosen by the users. Using parent-child relationships (or IS-A hierarchies) and treating attributes as first class objects (so that they can have attributes of their own) complex models can be easily specified. The system should provide a graphical editor/browser to define and navigate through knowledge components. Context sensitive menus must be provided for the users to define instantiate, modify, and link objects in the Meta model.

Support for Knowledge Capture

After the meta-model is defined, users should be able to create and modify process knowledge components and relationships among them using a using the graphical browser/editor. Each user may invoke the client GUI and connect to the same knowledge base maintained by the server. Thus, multiple users connected to the same server may conduct "conversations" in terms of the primitives specified in the meta-model. In these structured conversations each team member can add and modify various concepts and relationships among them. They may seek clarifications of concepts proposed by others. Using this facility the team members can communicate their viewpoints and expertise [27, 28] and map their views of the problem with those of others. In our example, the users may propose, suggest, elaborate on various issues, alternatives, justifications and assumptions. These knowledge components may be viewed (and modified if permitted) by other members of the team. They may, in turn, respond by proposing other concepts and relationships. With such a conversation, various viewpoints are exchanged among the members of the acquisition team. Thus the team members can clearly state their viewpoints, understand the viewpoints of others, map their views to those of others such that the team develops a shared understanding of the problem being solved.

Even when the discussions are conducted in the context of structured processes like the development of a house of quality, our system can be used to capture the process knowledge behind these activities.

Representation of Context

The larger context in which a participant has developed a particular perspective can be better understood by others if they have access to the details such as work products, supporting documents etc. These "sources" may also be available in various levels of formality (ranging from hypermedia documents to formal definitions). Quinn [54] refers to this as an elevation *from know how* to *know why (*knowing why a given choice was made over another), which he argues, makes a team more flexible and innovative when faced by a previously unseen problem. The system should support the specification of a variety of information about concepts that users specify: These knowledge chunks include:

- **What** information is represented - including salient attributes or characteristics.
- **How** this information- is represented both by formal and informal means- relates to other components of knowledge.
- **Who** are the stakeholders that played different roles in its creation, maintenance, validation and use**?**
- **When** this information was captured, modified and evolved
- **Where** it is represented **-** in terms of sources that "contain" this information.
- **Why** a certain concept evolved, or was created.

Links to Sources

An Acquisition Knowledge Management system should the ability to link most of this information as attributes of any concept. Also, a user can link a concept to the sources that provide additional information For example, each concept be linked to static documents or to documents dynamically created by searching the repository of hypermedia documents on the WWW. Further, a context sensitive menu may invoke external tools (such as a WWW gateway) to retrieve such documents that have been explicitly linked to an object, that are indexed with the keywords defined as attributes of the object and that are considered “similar” (using a variety of search techniques).

Assumption surfacing

The need to explicitly state the assumptions behind concepts has been discussed in recent research. As described in our meta-model, assumptions and their relationships to other assumptions and concepts can be captured using our system.

Review of Past Knowledge

The ability to retrace the various steps that were taken in the acquisition process can be very valuable. This would help the take corrective action when past mistakes are revealed. Further, such a review of knowledge is also useful to facilitate understanding of decisions, as well as for identifying the choice points where alternative decisions could lead to different solution paths. The team would benefit from a review to understand how the knowledge components were defined chronologically. Finally, the ability to selectively review the history focusing on select aspects of the problem will also be very useful.

The functionalities of our system to support such a feature should be based on the premise that a acquisition team may be interested in revisiting a decision process, including the *dead ends,* in the same (time) order in which it happened. Such a review is used in explaining the process and outcomes to new participants or as a training mechanism.

Dependency Management

The meta model discussed earlier provides ability to explicitly represent dependencies among various concepts such as assumptions. Our tools should include autonomous agents for maintaining dependencies at different levels of automation. For example, when a concept depends on another, the agents maintain the semantics of this dependency by propagating relevant properties of one concept to another. If a concept depends on an assumption, then the belief in that concept is based on the belief in that assumption. A major concern is that often the repercussions of changes in critical assumptions are not well understood, leading to very costly mistakes and rework. The facilities described here can mitigate such problems.

1.3.3 Mapping Functionalities to Requirements:

Table 2 maps the functionalities described above to the requirements identified in Table 1. Here, we identify the requirements that are addressed by each functionality. The current project will develop a rich set of functionalities for the Acquisition Knowledge Management system that will adequately address all of the requirements discussed in Table 1.

Table 2: Proposed System functionalities and requirements addressed by such functionality

System Functionality	Requirement(s) based on table 1
Definition of Concept Maps	{GI}, {VC},{DB}
Support for Knowledge Capture	{DR}, {NE}, {SM}, {NE}, {AT}, {CD}
Representation of Context	{DC} ,{NK}
• Links to sources	{MM}
• Informal and Formal components	{MM}
Knowledge Access	{NK}
Assumption Surfacing	{IA},{LA}
Review of past knowledge	{DP}, {DN}, {RE}
Agents for dependency management	{LA},{TA}

Bibliography

[1] P.S. Adler, Technology and the future of work (Oxford University Press, New York, 1992).

[2] J. Allen and P. Hayes, Moments and Points in an Interval Based Temporal Logic. Computational Intelligence, 5 (Nov) (1989).

[3] W. Applehans, A. Globe, and G. Laugero, Managing knowledge : a practical web-based approach (Addison-Wesley, Reading, MA, 1999).

[4] W.R.J. Baets, Organization learning and knowledge technologies in a dynamic environment (Kluwer Academic Press, Boston, MA, 1998).

[5] C. Baudin, C. Sivard, and M. Zweben, Recovering Rationale for Design Changes: A knowledge based approach, in: Proceedings of the IEEE proceedings, Los Angeles, CA,

[6] R. Bettis and M. Hitt, The New Competitive Landscape. Strategic Management Journal, 16 (1995).

[7] H. Bhargava, R. Krishnan, and A. Whinston, On Integrating Collaboration and Decision Technologies. Journal of Organizational Computing, 3 (4) (1994).

[8] R.E. Bohn, Measuring and Managing Technological Knowledge. Sloan Management Review, 36 (Fall) (1994).

[9] U. Borghoff and R. Pareschi, Information technology for knowledge management (Springer, New York, 1998).

[10] K. Carley, Organizational learning and personnel turnover. Organization Science, 3 (1) (1992).
[11] H. Chen, P. Hsu, R. Orwig, L. Hoopes and J. Nunamaker, Automatic Concept Classification of Text from Electronic Meetings. Communications of the ACM, 37 (10) (1994).
[12] R. Comerford, Pocket Computers Ignite OS Battle. IEEE Spectrum, (May) (1998).
[13] J. Conklin and M. Begeman, gIBIS: A hypertext tool for exploratory policy discussion. ACM Transactions on Office Information Systems, 6 (1988).
[14] N.R. Council, Improving Engineering Design: Designing for competitive advantage, National Academy Press, Washington DC (1991).
[15] A.W. Court, The Relationship Between Information & Personal Knowledge in New Product Development. International Journal of Information Management, 17 (2) (1997).
[16] D. Daetz, W. Barnard, and R. Norman, Customer integration : the quality function deployment (QFD) leader's guide for decision making (Wiley, New York, 1995).
[17] P. Darke, G. Shanks, and M. Broadbent, Successfully Completing Case Study Research: Combining Rigor, Relevance and Pragmatism. Information Systems Journal, 8 (4) (1998).
[18] T. Davenport, D. DeLong, and M. Beers, Successful knowledge management projects. Sloan management review, 39 (2) (1998).
[19] T.H. Davenport, Process innovation : reengineering work through information technology (Harvard Business School Press, Boston, 1993).
[20] T.H. Davenport and L. Prusak, Working knowledge : how organizations manage what they know (Harvard Business School Press, Boston, 1998).
[21] G.I. Doukidis, F.W. Land, and G. Miller, Knowledge-based management support systems (Ellis Horwood Halsted Press, Chichester New York, 1989).
[22] P. Drucker, The Post Capitalist Society (Harper Business Press, New York, NY, 1993).
[23] D. Duffy, Knowledge Champions: What Does it Take to be a Succesful CKO?, CIO Enterprise, (1998)
[24] W.E. Eder, Information Systems for Designers, in: Proceedings of the Proc. International Conference in Engineering Design, Harrowgate, 1307-1319.
[25] L. Fahey and L. Prusak, The eleven deadliest sins of knowledge management. California Management Review, 40 (3) (1998).
[26] J. Favela and C.J. Jerome, Accessing Corporate Memory in Networked Organizations, in: Proceedings of the Hawaii International Conference on System Sciences, Hawaii, 181-190.
[27] G. Fisher, et al., Making Argumentation Serve Design. Human Computer Interaction, 6 (1991).
[28] G. Fisher, et al., Supporting Indirect Collaborative Design with Integrated Knowledge Based Design Environments. Human Computer Interaction, 7 (1992).
[29] J. Galegher, R.E. Kraut, and C. Egido, Intellectual Teamwork: Social and Technological Foundations of Cooperative Wrok (Lawerence /Erlbaum Associates Inc., Hillsdale, New Jersey, 1990).
[30] L.H. Glickenhaus, Knowledge Transfer: Breaking Boundaries With Web-based Networks. Law practice management, 25 (2) (1999).
[31] F. Golshani, et al., Proceedings of the Sixth International Conference on Information and Knowledge Management : CIKM'97, November 10-14, 1997, Las Vegas, Nevada (ACM Press, New York, 1997).
[32] J. Grudin, Evaluating Opportunities for Design Capture, in: M. Carroll, Eds., Evaluating Opportunities for Design Capture, (Lawrence Erlbaum Associates, Mahwah, NJ., 1996).
[33] M. Hansen, N. Nohria, and T. Tierney, What's Your Strategy for Managing Knowledge? Harvard Business Review, (March-April) (1999).
[34] Hauser and Clausing, The House of Quality. Harvard Business Review, (3) (1988).
[35] M. Iansiti and A. MacCormack, Developing Products on Internet Time. Harvard Business Review, (September-October) (1997).
[36] A.R. Jassawalla and H.C. Sashittal, An examination of Collaboration in High Technology New Product Development Process. Journal of Product Innovation Management, (15) (1998).
[37] A. Khurana, Managing Complex Production Processes. Sloan Management Review, (Winter) (1999).
[38] N. Krishnakumar and R. Jain, Mobility Support for Sales and Inventory Applications, in: T. Imeluski and H. Korth, Eds., Mobility Support for Sales and Inventory Applications, 571-594 (Kluwer Academic Publishers, 1996).

[39] M. Lease, M. Lively, and J. Leggett, Using an Issue Based Hypermedia System to Capture the Software Life Cycle Process. Hypermedia, 2 (1) (1990).
[40] J. Lee, Sybil: A Qualitative Decision Management System, in: Whinston and Shellard, Eds., Sybil: A Qualitative Decision Management System, (MIT Press, Cambridge, MA, 1990).
[41] J. Lee, Design Rationale Capture & Use. AI Magazine, 14 (1993).
[42] D. Leonard-Barton and S. Sensiper, The Role of Tacit knowledge in Group Innovation. California Management Review, 40 (3) (1998).
[43] D.G. Lowe, Cooperative Structuring of Information : The representation of Reasoning and Debate. International Journal of Man Machine Studies, 23 (1985).
[44] J.G. March, Exploration and Exploitation in Organizational Learning. Organization Science, 2 (1) (1991).
[45] S. Mizuno, Y.o. Akao, and K. Ishihara, QFD, the customer-driven approach to quality planning and deployment (Asian Productivity Organization, Tokyo, Japan, 1994).
[46] K. Morik, et al., Knowledge representation and organization in machine learning (Springer-Verlag, Berlin ; New York, 1989).
[47] R. Morrison and J. Kennedy, Advances in databases : 14th British National Conference on Databases, BNCOD 14, Edinburgh, Scotland, United Kingdom, July 3-5, 1996 : proceedings (Springer, Berlin ; New York, 1996).
[48] J. Mylopoulos, Telos: Representing Knowledge about Information Systems. ACM Transactions on Information Systems, 8 (1990).
[49] C.K. Nicholas and J. Mayfield, Intelligent hypertext : advanced techniques for the World Wide Web (Springer, Berlin, [Germany] ; New York, 1997).
[50] I. Nonaka, The Knowledge Creating Company. Harvard Business Review, (November-December) (1991).
[51] I. Nonaka and N. Konno, The Concept of "Ba": Building a foundation for Knowledge Creation. California Management Review, 40 (3) (1998).
[52] I. Nonaka and H. Takeuchi, The knowledge-creating company: how Japanese companies create the dynamics of innovation (Oxford University Press, New York, 1995).
[53] W. Orlikowski and J. Baroudi, Studying Information Technology in Organizations: Research Approaches and Assumptions. Information Systems Research, 2 (1991).
[54] J.B. Quinn, P. Anderson, and S. Finkelstein, Managing Professional Intellect: Making the Most of the Best, Harvard Business Review, March-April (1996)
[55] B. Ramesh and V. Dhar, Supporting Systems Development using Knowledge Captured during Requirements Engineering. IEEE Transactions on Software Engineering, (1992).
[56] B. Ramesh and K. Sengupta, Multimedia in a Design Rationale Decision Support System. Decision Support Systems, 15 (1995).
[57] V. Rao and R. Goldman-Segall, Capturing Stories in Organizational Memory Systems: The Role of Multimedia, in: Proceedings of the Hawaii International Conference on System Sciences, Hawaii, 333-341.
[58] Robillard, The Role of Knowledge in Software Development. Communications of the ACM, 42 (1) (1999).
[59] R. Ruggles, The state of the notion: Knowledge management in practice. California Management Review, 40 (3) (1998).
[60] R. Sanchez and A. Heene, Strategic learning and knowledge management (Wiley, Chichester New York, 1997).
[61] P.M. Senge, The fifth discipline : the art and practice of the learning organization (Doubleday/Currency, New York, 1990).
[62] M. Shaw and M.Fox, Distributed artificial intelligence for group decision support. Decision support systems, 9 (1993).
[63] M.L. Shillito, Advanced QFD : linking technology to market and company needs (Wiley, New York, 1994).
[64] M. Song and M. Montoya-Weiss, Critical Development Activities for Really New versus Incremental Products. Journal of Product Innovation Management, 15 (1998).
[65] S. Srivastva, The executive mind (Jossey-Bass, San Francisco, 1983).
[66] E.W. Stein and Z. Vladimir, Actualizing Organizational Memory with Information Systems. Information Systems Research, 6 (1) (1995).

[67] G. Szulanski, Exploring Internal Stickiness: Impediments to transfer of Best Practice Within the Firm. Strategic Management Journal, 17 (Winter) (1996).
[68] D. Teece, Research directions for knowledge management. California Management Review, 40 (3) (1998).
[69] R.E. Teigland, C. Fey, and J. Birkinshaw, Knowledge Dissemination in Global R&D Operations: Case studies in three multinationals in the high technology electronics industry., Stockholm School of Economics, Stolkholm (1998).
[70] D.R. Tobin, The knowledge-enabled organization : moving from "training" to "learning" to meet business goals (Amacom, New York, 1998).
[71] S. Toulmin, The Uses of Arguments (Cambridge, Cambridge, UK, 1958).
[72] S. Toulmin, R. Rieke, and A. Janik, An Introduction to Reasoning (MacMillan, New York, 1984).
[73] M.A. Von-Glinow and S.A. Mohrman, Managing Complexity in High Technology Organizations (Oxford University Press, New York, 1990).
[74] K.B. Yakemovic and E.J. Conklin, Report on a Development Project Use of Issue Based Information System, in: Proceedings of the Computer Supported Cooperative work, 105-118.
[75] R. Yin, Case Study Research: Design and Methods (Sage Publications, Thousand Oaks, CA, 1994).
[76] Zack, An Architecture for Managing Explicated Knowledge. Sloan Management review, Spring

(1999).

2 Supporting Acquisition of Information Products

2.1 Introduction

In this section we focus on the acquisition of information products, a complex acquisition activity. The Internet provides the medium and digital information products (IPs) represent elusive "commodity" that have long been the capital market economist's dream—a marketspace and the product with which third-degree price discrimination is possible. An unprecedented surge in the trade of information products (IPs) has resulted from the widespread adoption of the Internet. Information products consist of a highly interdependent, primarily intangible package of information. They cannot be physically inspected *before* purchase, and traditional trading mechanisms provide no advantage over electronic ones [1]. The Internet has provided a channel for the distribution and trade of such products at low overhead costs [1, 2]. When distributed over such a medium, their variable cost of production and distribution approaches zero, as the product has no physical form (unlike retail packaged software or non-digital information products). However, their intangible nature also causes severe competitive market challenges [1, 2] that only worsen because of their low economic cost of reproduction coupled with high fixed costs [2].

The centricity of knowledge in various activities of post-industrial businesses, including IS organizations is well recognized in recent research. Knowledge based activities are increasingly becoming the primary internal function of firms [3, 4] wherein their competencies are largely determined by their ability to manage knowledge work and emergent knowledge assets that eventually drive most productivity gains [5]. Knowledge workers and their productivity are indeed the most valuable assets of the 21st century organization [6]. We begin this chapter by defining information products and comparing their knowledge-centricity with that of physical products. Then we map knowledge-based technology facilitated solutions to the problems identified in earlier. We then describe a design decision supported system that addresses a select set of problems involved in complex IPD. We conclude with a discussion of related work, outline the limitations of our work and planned future work.

2.1.2 Defining Information Products

An information product is defined as a highly interdependent package of information [7] that is capable of being distributed in digital form [2]. Software engineering products, CD-ROM databases, print-on-demand services, electronic libraries, electronic newspapers, and Web content are examples of such products [8, 9]. In economic terms, the fixed costs associated with their production are high and the variable costs are relatively low [2]. If left to the market place, the price of an information product will be low due to its low marginal cost of reproduction. Furthermore, because such products are experience goods, their pricing is *perceived* value-based, and not cost-based [10]. If consumer perceived value is maximized through robust design and maintenance processes, sustainable increasing economic returns can be generated through self-reinforcing positive network feedback [7, 10]. These factors necessitate differentiation among information products, as perfect competition can spell disaster for the producer(s) in the product's markets [2, 8].

2.1.3 IPD as a Knowledge Intensive Activity

Information product markets are dynamic in terms of growth and the pace of new product introduction [8]. Development of information products is a knowledge intensive activity [9, 11], and products in the information industries have high levels of embedded knowledge content [12]. As a firm gains experience through the development of information products, much of the lessons learned remain captured as information [7, 13] that is applied i.e. converted to knowledge [14]. As teams in an organization engage in the development of new products and services, the underlying rationale used to make decisions at various points in the design process need to be effectively captured and reused [15, 16] to provide support for decisions in later projects or in the production of subsequent product versions [17]. Therefore, it is critical to be able to manage and reapply lessons learned and design decisions made in earlier projects in similar contexts in order to keep the product competitively viable. Effectiveness management of knowledge associated with the design of their products and services facilitates purposeful opportunism [17] in their offerings. This necessitates a closer examination of the role of knowledge in the design process, and mechanisms for supporting it.

2.2 Characteristics of an IPD Design Knowledge Management System

Following the challenges identified in the preceding section, we examine deliberate approaches for managing design knowledge to mitigate associated problems. Tracking the history of design decisions [9] can help information product designers account for changes in design assumptions and evolving market needs [2]; maintenance of traces for abandoned and interrupted design decisions can help avoid rework [9]; metadata on past decisions can help designers apply and reuse historical *lessons learned* [7]. Our work is based on the premise that if knowledge about the history of design is captured and maintained, it can alleviate many of these problems associated with IPD. The challenge then is to represent this historical record in a way that it supports decision-makers involved in the development of an information product, and in a manner that is neither obtrusive nor imposes high overhead resource costs.

As our research is geared towards developing KMS for this purpose, it is focused on capturing and representing knowledge about the decisions made during IPD process. Recent research recognizes that maintaining knowledge about just the decisions themselves is not sufficient to foster shared understanding among IPD participants; the historical context of various decisions must also be maintained [9].

2.2.1 Mapping IPD Problems to System Goals and Characteristics

Recent research on information products proposes several goals for supporting distributed coordination and design decision making in IPD [7]. In Table 3, we map these goals to problems identified in §3, and further translate these goals into enabling technology solutions. These goals are then used to provide the foundation for our knowledge management system. The first column in Table 3 describes the goals as described by Fielding et al. [7]. IPD challenges from §3 are represented by their corresponding codes in the second column. Enabling technologies to support IPD processes are identified in Column 3.

Table 3: Enabling technology for design decision support in distributed collaborative IPD

Goal [7]	IPD problems addressed	Enabling technology for design decision support
Distributed coordination and design decision making	{SU}, {RS}, {RM}, {IV}	All of the below
Linking artifacts to processes	{LC}, {RM}	Links between process knowledge and artifacts
Flexible interaction model and hypermedia services	{PK}, {UA}	Formal and informal media; hyper-media links
Distributed annotation	{SU}, {RM}	Distributed annotation of artifacts with concept maps
Distributed authoring	{LS}, {IV}	Distributed authoring of process knowledge and concept maps
Visibility of artifacts over time	{LC}, {RS}, {PK}	Recording of design development history / process knowledge

2.3 Toward a Mechanism for Supporting IPD Knowledge

We have developed a design decision support system to provide a variety of enabling technologies identified in Table 3. The facilities provided by this system include:

- A Web-based collaborative environment in which the various participants can conduct deliberations leading to IPD decisions
- Facilities for capturing the context in which these decisions are made. Using a distributed multimedia annotation system, the decisions and the rationale for these decisions can be linked to the artifacts, supporting documents and other related information on the WWW.

- A facility to manage the complex network of dependencies among the various components of knowledge often thinly spread across the various participants in collaborative teams.
- A facility for intelligent retrieval of components of design decision knowledge based on ad-hoc requirements of the various participants.
- A mechanism to maintain the consistency of the captured knowledge so that the knowledge is current and accurate

2.3.1 Linking Artifacts to Processes

Kline et al. [61] stress the importance of integrating tools for supporting collaborative work within the context of the work environment. We provide a variety of support mechanisms to address this issue: We recognize the importance of relating process knowledge to the artifacts that are outcome of the processes. We provide a model for capturing deliberations in which components of process knowledge (such as requirements, assumptions, decisions, assumptions etc.) can be captured. For example, conversations may be conducted using REMAP, a model based on the IBIS argumentation model [47]. Using our tool, users can not only capture details of the deliberations, but also maintain links to the artifacts that are the “inputs” and “outputs” of these deliberations. The components of a deliberation on the production different versions of a CD-ROM IPD can have embedded in them, links to the actual code (represented in the HTML format). Similarly, a link embedded in the artifacts can be used to retrieve a discussion related to its creation and maintenance as shown in Figure 2.

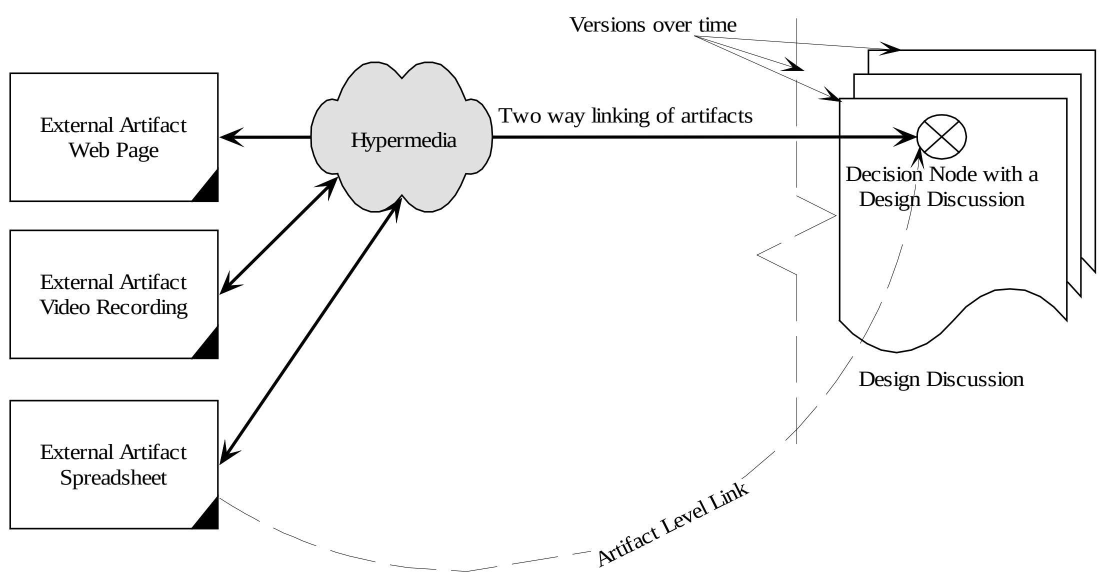


Figure 2: Linking artifacts to processes in temporally distributed, collaborative hyperspace

2.3.2 Flexible Interaction Model and Hypermedia Services

Design history can be represented in varying degrees of formality. Formal representations can help automated reasoning, but are difficult to develop in most complex, dynamic design situations. Whereas informal descriptions help create thick descriptions, indexing, retrieval and formal reasoning with such information can be difficult. We provide the flexibility to represent process knowledge in a variety of forms ranging from formal specifications to hypermedia objects. For example, the belief in an assumption can be represented formally, whereas, the video /audio clips of discussions involving demonstrations of various versions of the IP can be represented using hypermedia. Depending on the complexity and importance of a decision, the rationale behind it may be captured at different degrees of detail. Our system provides the flexibility to represent decision rationale at different levels of granularity or detail. In the simple view, the users can annotate their decisions with notes and assumptions. In the detailed view, however, they can create a complex network of requirements, issues, alternatives, arguments and assumptions that were critical in arriving at a decision.

2.3.3 Distributed Annotation

Boland and Tenkasi [62] argue that it is essential to support explicit representations for exchange of views and undertakings among distributed team members. We support explicit representation of ideas and viewpoints using concept maps. These maps can be used by the participants to create detailed representation of the variables and assumptions used by them in defining problem and solution spaces. In complex situations, team members may use different variables to describe both problem and solution spaces. Further, different members of a team may use the same term with different meanings. The concept maps representing such information can be thought of as annotations [62] explaining the viewpoints of individual participants that contributed to the development of the information product. Consider the scenario in which an editorial staff member proposes a layout of the WWW version of a newspaper that prominently places an editorial segment. This team member may explain the philosophy behind her design by clearly identifying the variables she considers important in prioritizing various segments to be accommodated in the newspaper. This ability to link knowledge about the problems and solutions to the artifacts can be used by the various team members to created distributed annotations on the information products developed collaboratively.

2.3.4 Distributed Authorship

Our tool is based on a client server architecture in which clients may be distributed over local or wide area networks. The clients connect to a centralized knowledge base to retrieve, define and modify components of process knowledge and concept maps. This architecture supports distributed authoring by team members.

2.3.5 Visibility of Artifacts over Time

A major concern with the development of information products is loss of knowledge about the history of the evolution of information products over time, which leads to many of the problems discussed in section 3. For example, the current layout of an online newspaper can be best understood only if the previous versions of the layout as well as the reasons behind the changes made to the prior versions that led to the current version are readily available. Our system provides the facilities to capture this information about the history of evolution. By capturing the various issues considered, the alternative solutions proposed, the arguments supporting and opposing each of these alternatives and the assumptions behind each of these, the designers can explicitly articulate the rationale behind the evolution of their artifacts over time. In the following section we describe our prototype that illustrates these characteristics.

2.4 Design Knowledge Management System

Our KMS provides facilities for defining, browsing and modifying knowledge about history of development of information products. We illustrate the capabilities of the system using scenarios on the development of various versions of an online newspaper.

2.4.1 Linking Artifacts to Processes

Consider the situation in which a team of developers is involved in designing the layout of the newspaper. Several participants contribute to this important decision. They range from the editors in charge of the various sections such as sports, business, technology etc. as well as functional areas such as marketing that is responsible for the sale of the paper and advertising that is responsible for generating advertisement revenues. The discussions among these team members may be conducted using our tool. Figure 3 shows the results of such a discussion. The discussion centers on the requirements for designing the front page of the layout. Varieties of concerns or issues that are raised by the team members include the following:

- Does information about weather belong in the front page?

- Does information on sports scores belong in the front page?

Each of these issues in turn may lead to more specific questions such as where in the front page will the weather information be? How much space should be allocated in the front page for the weather information? The team members involved in the weather section may propose alternative solutions. For example, a team member suggests that this segment belongs in the banner based on the argument that it will provide high visibility. This argument is based on the assumption that the target audience desires such a high visibility placement of weather. Similarly, other team members propose different alternatives. They also support and / or oppose the various alternatives. This structured conversation, shown in Figure 3, is conducted using REMAP (an extension of the IBIS model) in which users can raise issues or questions, suggest alternatives to solving the issues, provide arguments supporting and objecting to the various alternatives and identify critical assumptions that need to be explicitly understood. Our tool provides the ability for the users to define any such model of conversation by specifying the nodes and links that define the legal moves. Figure 3 also shows a fragment of a discussion on the placement of sports scores. Each of the proposed alternatives has a direct effect on the final layout to be chosen. Based on the evaluation of the various alternatives (to be discussed in more detail below) the team makes a decision to choose one of the alternatives. Our tool provides the ability to hyperlink this decision to the corresponding layout design. Thus, the rich history behind the choice of the layout is captured in detail and linked to the artifact itself.

A field study [65] established the feasibility and usefulness of capturing conversations such as those illustrated in Figure 3 in complex information product development activities. However, in any complex problem solving activity such as information product development will involve the use of a variety of tools such as groupware systems and email to facilitate informal and formal interactions, synchronously as well as asynchronously. Integration of our system with outputs from such sources of knowledge is essential for group cohesive and non-intrusive capture of process knowledge. As an initial step, we provide facilities for linking structured and unstructured knowledge components. The capture and maintenance of process knowledge can be very expensive. Therefore, non-intrusive and easy capture of this information is essential for successful adoption of our tools. We illustrate such integration with an example on the capture of process knowledge from electronic mail exchanges.

Figure 4 shows the output of an email exchange among the members of the IPD team. A team member is reviewing an email that addresses the issue of placement of weather information on the front page of the newspaper. While using her familiar tool for such exchanges (Microsoft outlook, in this case), she highlights a portion of a mail message as relevant for the focused discussion that was illustrated in Figure 3. Notice that the Microsoft outlook window has customized menu options such as “set connection,” copy to REMAP etc. Our system provides access to knowledgebase containing the conversations illustrated in Figure 3 through such menu options from common productivity tools such as Microsoft office tools. From any of these tools, a user can connect to the knowledgebase and highlight and copy information in these tools (text, spreadsheets, database tables etc) and "send" them to the knowledgebase. In our example, the user highlights text corresponding to the argument about following the competitor's strategy and sends it to the knowledgebase. In a subsequent synchronous or asynchronous meeting (with the tool shown in Figure 3) this fragment of process knowledge can be linked to other relevant pieces to provide complete traceability to the various components of the discussion. Such a facility, enabling users to work within their familiar environments but providing the ability to incrementally acquire knowledge about IPD, which is strongly supported by Klein [63]. Our approach also recognizes the importance of relating process knowledge to the artifacts that are the outcome of the process. Specifically, various objects in our semi-structured process knowledge components such as requirements, assumptions, decisions, constraints etc. relate the deliberations to the context in which they occur. Further, our approach supports a wide spectrum of representations (from formal to hypermedia) to facilitate the capture of process knowledge in its most natural and useful form. This is similar in spirit to the call for representing artifact evolution as a component of rationale advocated in the DICE project [64]. Our efforts at providing a tailorable environment in which different primitives could be used for conducting conversations is a first step towards this goal.

2.4.2 Flexible Representation and Hypermedia

In the above scenario, the representation of history behind design decisions was guided using the primitives of an extended Issue Based Information System model [47, 65]. However, the tool provides the flexibility to customize the representation in a number of ways. First, simply changing the schema that represents the nodes and links in the model of collaboration may use a different conversation protocol. Second, we recognize that a team may wish to represent the history behind decisions at varying levels of detail or granularity. The discussion in Figure 3 represents a very detailed model. Instead, the users may switch to a simple model in which only the decision and the assumptions may be recorded. By providing this flexibility, the tool enables the capture of history at the desired level of detail. Two-way linking between the artifacts and the design history is provided by the ability to embed the reference to any specific discussion within any hypermedia document. For example, various segments of a layout represented in the hypermedia format may have references to the discussions corresponding to that choice. A user can therefore seamlessly move from the discussion to the artifact and vice versa.

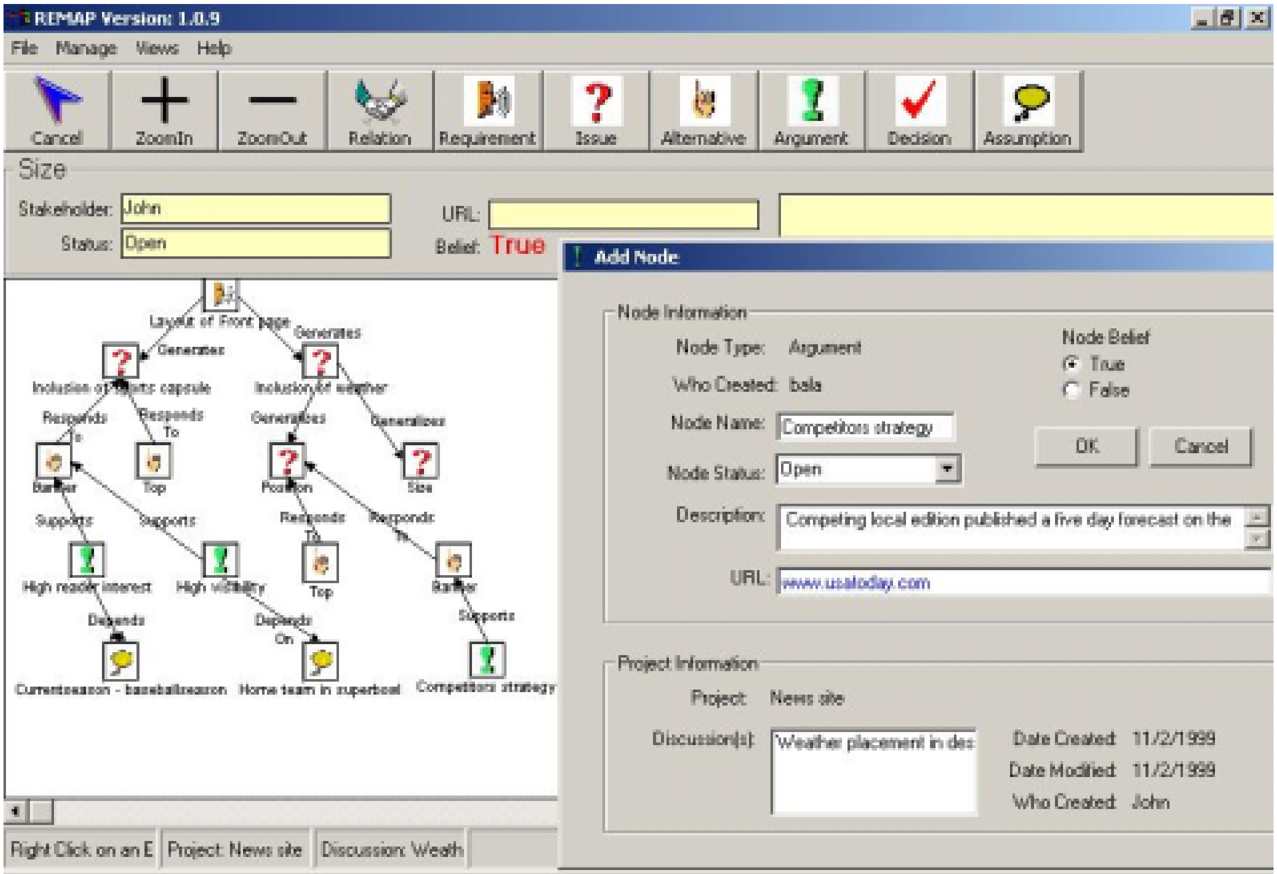
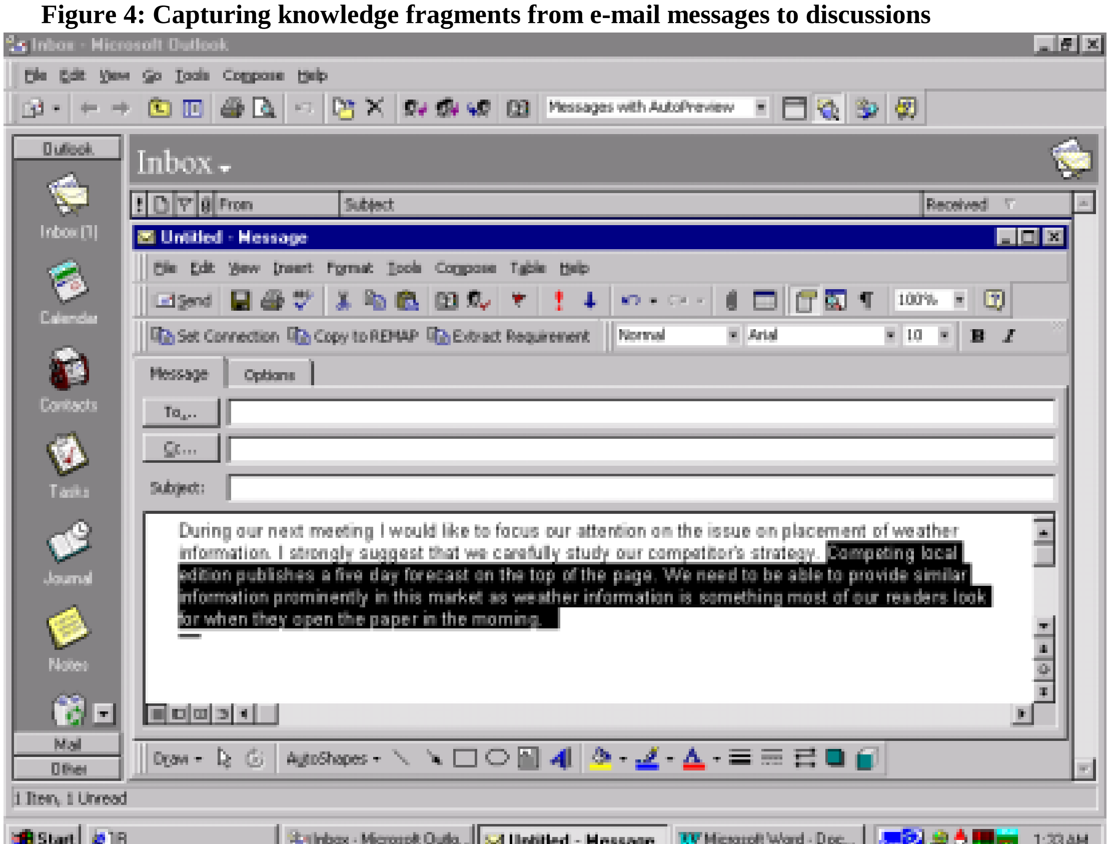


Figure 3: A design decision discussion with two way links between artifacts.

Figure 4: Capturing knowledge fragments from e-mail messages to discussions



The need to represent the context in which decision are made is supported in our model by the ability to hyperlink any node in the model to hypermedia documents. For example, the alternative to use a weather strip at the bottom of the page may be supported by the argument that it is the format employed by a competing publication. A hyperlink to that publication may be created to completely capture the context in which this argument was made (see Add Node insert in Figure 3).

2.4.3 Distributed Annotation

The tool supports distributed annotation with concept maps. Again, the concepts to be used to help communicate different viewpoints may be specified by the team members. For example, a team may use decision variables as the concept of interest. Each member of the team involved in layout design may describe the various variables that they consider as important in arriving at a layout. Marketing and Advertising may be interested in attractive design and potential for increased advertising revenues respectively as their top priorities. The other team members may seek clarifications on these concepts to fully understand the respective viewpoints. Marketing may elaborate on its choice to mean the use of color and rich media as enhancing the attractiveness of the design. Similarly, other team members may use this facility to specify their choices and elaborate on them. This ability to exchange viewpoints enhances the chances for shared understanding among team members, which is essential for successful collaboration.

2.4.4 Distributed Authoring

Our prototype KMS supports distributed development of information products with client server architecture. The clients can be invoked from a Web browser. The team members using the client interface can connect to a central knowledge server that maintains process knowledge components. This facilitates distributed authoring of design history and concept maps by the team members.

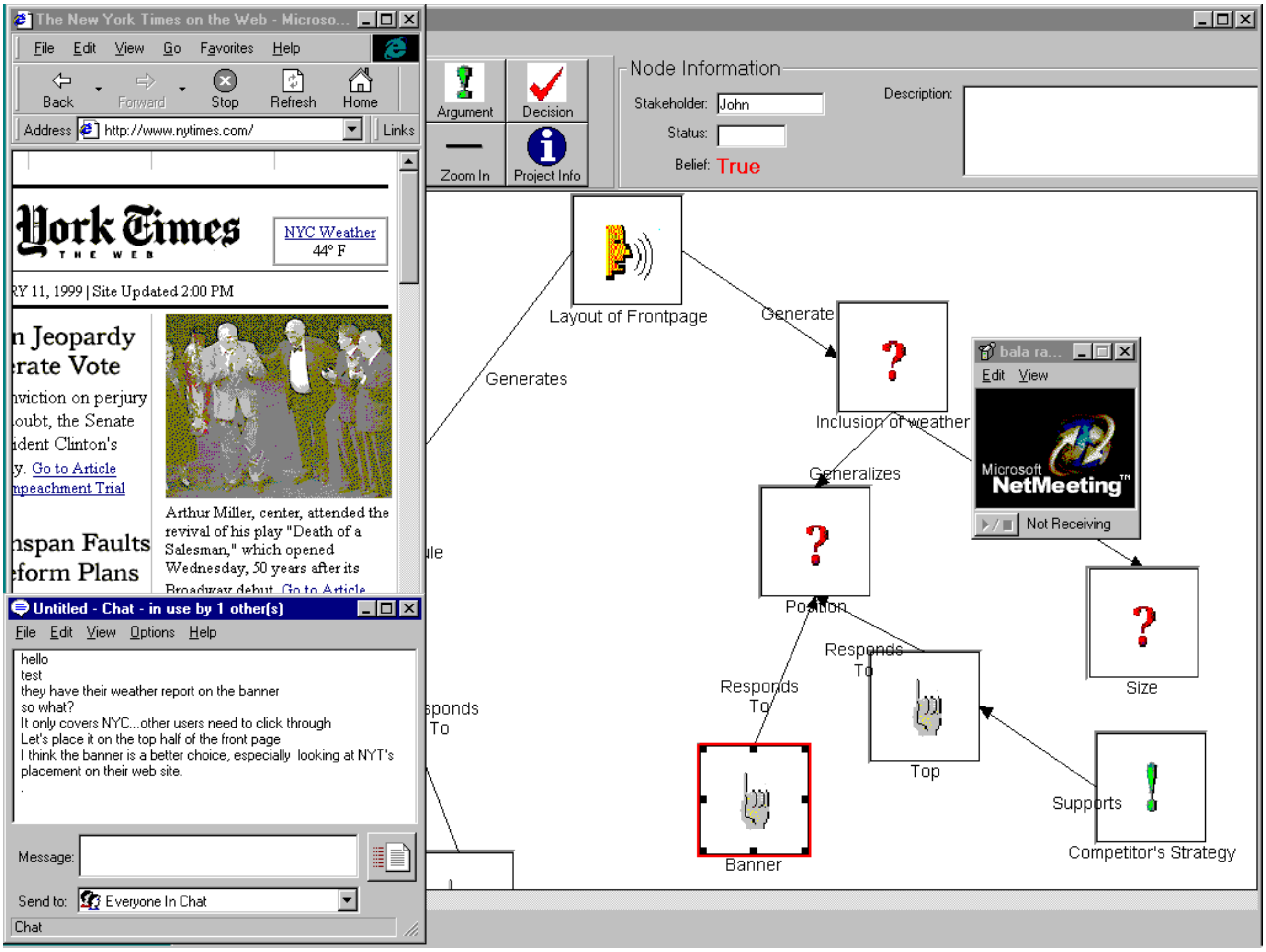


Figure 5: Distributed authoring, links to external knowledge sources (in this case, a competitor's site) and relevant real time deliberations can be captured and linked to design decisions as they are made

Figure 5 illustrates the use of the KMS in conjunction with Netmeeting, a collaboration support environment. The IPD team is engaged in the discussion on the position of the weather segment in the front page using the chat utility. A team member who suggests positioning weather in the banner, shares a Web browser that displays the competitor's design. Our system complements Netmeeting's ability to support conversations and share applications in a number of ways. The essential aspects of unstructured conversations conducted within Netmeeting, can be captured within our tool in a semi-structured format. Segments of the conversations can be directly imported into the nodes in our network of design history. Further, the artifacts themselves can be two-way linked to the contents of the conversations. As mentioned earlier, the competitor's Web page can be linked to the argument and the decision to the layout that displays weather in the intended position.

2.4.5 Decision Support with Visibility of Artifacts over Time

Our tool provides a variety of decision support aids to not only capture knowledge about the history of development, but also to maintain the consistency of such knowledge and perform automated decision support with that knowledge, especially when the context in which the decisions are made change. Recall that the validity of the alternatives proposed also depends on the validity of the assumptions behind these alternatives. Simon [66] suggests that all stakeholders involved in the delivery of a product must be involved from its inception. He gives an example of manufacturing industries where the failure to consider manufacturability at an early stage usually causes extensive redesign with a product, thereby causing major delays in production and subsequent delivery [66].

Consider the suggestion to use the banner for weather is based on the assumption that the customer market segment desires such a high visibility placement. The marketing department may be asked to evaluate this assumption. If they invalidate this assumption, then the system propagates the effects of this assertion to invalidate the decision. Similarly, the evaluation of the assumption about the current interest in the sports segment may lead to the validation of the alternative to use the banner for sports scores. This ability to dynamically synthesize the layout based on process knowledge can be very valuable in a variety of ways. For example, two editions of the same paper produced in different cities may be composed with different layouts based on their specific conditions (whereas sports may be at the top priority for a city in Southern California hosting a sporting event, weather may be most appropriate for a city in the north east facing a major storm). First, the system helps synthesize these designs based on a common and consistent set of design principles discussed by the team members. Second, when the context in which the decisions are made changes (which is common in the development of information products like an online newspaper where new stories of high importance may develop at any time), the system helps rapidly identify components of the design that are valid. Finally, the history of the development of the information product is captured in its complete form so that the teams will have access to this information when designing other versions of the product. Our system supports ad-hoc queries to retrieve components of this history to support decision-making. For example, a design team may want to review what the layout looked like when similar conditions existed in the past and more importantly, why so? The ability to access and reuse such information will be extremely valuable.

2.5 Implementation of the prototype system

The prototype system is based on the REMAP, en environment to support collaborative decision support and traceability. The conceptual models used in this research were implemented and validated using ConceptBase, an implementation of the high level conceptual modeling language *Telos*

[73]. Telos is based on a first order assertion language and provides facilities for specifying meta-concepts, semantic integrity constraints and deductive rules. Using meta-concepts, meta models that represent various classes of knowledge can be specified and instantiated. The language implements Allen's temporal calculus [74], offering powerful temporal reasoning capabilities. The prototype is based on a client server architecture and supports group work. Users of the system spread across a network can communicate with each other through a centralized knowledge server. The server maintains the integrity of the integrity of the process knowledge components. The system provides a graphical user interface for communication with the server to retrieve and modify the contents of the knowledge base. Further, the browser provides links to external tools such as a WWW gateway.

Our prototype system employs autonomous agents for maintaining dependencies at different levels of automation. For example, when a concept depends on another, the agents maintain the semantics of this dependency by propagating relevant properties of one concept to another. If a concept depends on an assumption, then the belief in that concept is based on the belief in that assumption. Using deductive rules, the autonomous agents propagate these beliefs.

A major concern for in complex acquisitions such as new systems development is that often the repercussions of changes in critical assumptions are not well understood, leading to very costly mistakes and rework. For example, the change in the validity of an assumption, for example, can have serious repercussions throughout the development process. Returning to the scenario discussed in Figure 5, the critical decision on where to locate a particular section in a newspaper hinges on, among other things, the assumption about the competitor's strategy. The decision making process proceeds with the assumption that the competitor places the sports section in the top part of a page. Though this decision may be valid now, it may become invalid at a later point in time. When this occurs, the validity of the argument to place the sports section at the top section is loses support.. When this occurs, the system will be able automatically detect this problem and suggest reevaluaation of the decision.

Similarly, the dependencies in the network of issues that get discussed, the various alternative solutions considered and their attendant justifications are captured and maintained by autonomous agents with different levels of formality. In the simple case, the system warns the user about changes in relevant concepts on which the concept of interest to him/her depends. In the other extreme, changes to concepts are automatically propagated. A network of dependencies can be set up among any concept described using our system. In our example above, instead of automated propagation of the beliefs due to changes in the assumption, the user may be notified to highlight the decision about the location of the sports section needs to be reexamined.

2.6 Related Work

Many tools for capturing design rationale proposed in the literature use argumentation models such as issue based information systems gIBIS [65]. Tools such as [65] and IBE [67] provide only passive support for the capture of rationale. In contrast, we advocate active support for both capture and use of history. Our work is similar in spirit to that of the SYBYL project [68] in providing automated reasoning tools. Our work extends this support further by providing mechanism for distributed coordination with annotation and authoring, as well as providing links between artifacts and design history. The need for hypermedia annotation of artifacts has been suggested by prior research [69]. Our approach extends such proposals by documenting detailed design history in a semi-structured way so that automated support for the use of this information can be provided. This research differs from earlier work on the capture of semi-structured history information exemplified by tools that support IBIS and its extensions [47, 65] in its focus on providing a tight integration between the process knowledge and the artifacts themselves. In the domain of information product development, the tight integration between the process knowledge components and artifacts themselves can be maintained. The synthesis of a design solution can readily be supported when the context for the design decisions change. Thus, whereas the focus of decision support in the current research is the *synthesis* of information products, prior research has concentrated on providing access to history to help design teams working in the later phases of a project or a future project. The scope for opportunistic planning and synthesis are high in IPD [9] and our decision support tools are geared towards supporting these activities. Recent studies on the use of structured argumentation techniques to capture organizational memories suggests that complex models are appropriate for some "wicked" problems whereas simpler schemes are more appropriate for other contexts [70]. This finding supports our approach of supporting the capture and use of history at multiple levels of abstraction or detail. Though the WWW has emerged as an important medium for the production and delivery of information products, the current WWW infrastructure has several missing elements for the development of annotation systems. We have proposed an annotation system that complements the capabilities currently available on the WWW.

2.7 Limitations and Future work

The capture of knowledge about the history of development can be very expensive. However, studies in the domain of software engineering (such as [71]) document the feasibility and usefulness of such efforts even in large-scale projects. Even in domains where the tight integration of design process knowledge and the artifacts cannot be easily maintained, the benefits of maintaining comprehensive design history have been observed [72]. Due to the tight integration between process knowledge and the information products themselves, the benefits of design history information can be significantly higher. Bellander [19] notes that such a process oriented approach to publishing is generalizable to a certain level of granularity for all companies developing such products. While our example discussed a scenario involving layout and content issues in the development of information products, it can also be applied to other IPD processes such as color configuration in the product planning stages, "repurposing" components of an information product and distribution [19]. However, detailed empirical studies crucial to establish the effectiveness of the approach proposed here is the subject of ongoing research.

We are also exploring ways to support the non-intrusive capture of process knowledge with mechanisms such as concept classification of group meeting transcripts and electronic mail exchanges. Such automated support for the use of captured knowledge is likely to greatly enhance the usefulness of this knowledge. We seek to provide stakeholders in IPD with comprehensive support tools for facilitating effective groupwork.

Our future work is planned in two phases as follows:

- In phase I, our primary objective is the development of a knowledge management system to facilitate the creation and use of process knowledge documenting **traceability** to critical outputs of an acquisition activity. We focus on developing such a system centered around the concept of **traceability** defined as **the ability to follow the life of a (physical or conceptual) object, from its origins to its use**
- In phase II, a traceability based process knowledge management system will be used to create a knowledge network, i.e., a network of people and information systems associated with collaborative, knowledge intensive tasks. Such a process knowledge management system should provide mechanisms for creating, finding, packaging, maintaining, and applying both tacit and explicit knowledge.

The first phase of the planned work is motivated by our recent work on the development of reference models and tools for *requirements traceability* in large-scale systems development. This work demonstrates that the efficiency and effectiveness of traceability as a mechanism for managing complex processes. Extending this work, suggest that traceability gives essential assistance in understanding the relationships that exist within and across various artifacts produced during the acquisition process. These relationships help establish that trace of the process through which critical acquisition decisions are made and help ascertain how and why outputs of an acquisition process satisfy stakeholder requirements. In short, traceability is a characteristic of an acquisition activity in which the requirements are clearly linked to their sources and to the artifacts created by the acquisition process.

Formally speaking, a traceability system can be defined as a semantic network in which nodes represent objects (also stakeholders and sources), among which traceability is established through links of different types and strengths. However, this begs the question which node and link types *should* be defined to support specialized activities such as acquisition activities. We propose the use of empirically derived reference models for traceability among objects, stakeholders and sources in acquisition activities.

Our extensive studies on theoretical and empirical foundations of traceability practice in system engineering suggests such an approach. This will involve the development of reference models comprising the most important kinds of traceability links for various acquisition tasks. Reference models are prototypical models of some application domain, usually organized according to some underlying basic metamodel. The purpose of reference models is to reduce significantly the task of creating application-specific models and systems: the user selects relevant parts of the reference model, adapts them to the problem at hand, and configures an overall solution from these adapted parts. Reference models are therefore an abstraction of best practice and derive their relevance from the slice of practice they cover. The references models developed in this study will be developed within the context of complex acquisition activities to address the research questions identified above. Further, the traceability links so derived can be classified to develop more concrete semantics. With such a well-defined reference model, we can construct and validate a process knowledge management system to support the tasks of various participants in the acquisition process, also specifically addressing the dimensions addressed in the research question

An important aspect of the proposed project is the use of the KM infrastructure developed to develop a knowledge network to support acquisition. The KM system developed in this research aims at capturing organizational knowledge in its most complete form to facilitate knowledge networking. This system can be tailored to support knowledge networking among distributed collaborative development team members. Using its web interface, a Web-based knowledge networking environment can be supported, in which the various participants can conduct deliberations leading to product development decisions. Using the system's ability to handle multimedia, a distributed multimedia annotation system to facilitate thick descriptions of knowledge in a knowledge network can be developed. Further, the consistency of the captured knowledge can be maintained with a reason maintenance system. We further propose the integration of the tool with collaboration tools such as NetMeeting to facilitate synchronous knowledge exchange as well as with tools used in the normal work environment such as Rational Rose and Microsoft Office to help the capture and use of knowledge without loss of context. This project recognizes that to facilitate indexing, retrieval, integration, and understanding the various user categories in the knowledge network, information components that address that various facets (What, Who, Where, How, Why and When dimensions) must be addressed.

2.7 Related Publications

Ramesh, B. and M. Jarke (2001). "Toward Reference Models for Requirements Traceability." IEEE Transactions on Software Engineering **27**(1): 58-93.

Ramesh, B. and K. Mohan (2001). Integrating Group Decision and Negotiation Support Systems with Work Processes. Hawaii International Conference on System Sciences, Maui, HI.

Ramesh, B. and A. Tiwana (1999). "Supporting Collaborative Process Knowledge Management in New Product Development Teams." Decision Support Systems **27**(1-2): 213-235.

Tiwana, A. and B. Ramesh (2001). "Integrating Knowledge On the Web." IEEE Internet Computing May/June: 32-39.

Tiwana, A. and B. Ramesh (2001 (forthcoming)). "A Design Knowledge Management System to Support Collaborative Information Product Evolution." Decision Support Systems.

Bibliography

[1] D. Koppius, "Dimensions of Intangible Goods," presented at 32nd Hawaii International Conference on system Sciences, Maui, Hawaii, 1999.

[2] C. Shapiro and H. Varian, "Versioning: The Smart way to Sell Information," *Harvard Business Review*, pp. 16-114, 1998.

[3] J. B. Quinn, P. Anderson, and S. Finkelstein, "Managing Professional Intellect: Making the Most of the Best," in *Harvard Business Review*, 1996, pp. 71-80.

[4] T. H. Davenport, *Process innovation : reengineering work through information technology*. Boston: Harvard Business School Press, 1993.

[5] Davenport, Jarvenpaa, and Beers, "Improving Knowledge Work Processes," *Sloan Management Review*, pp. 53-65, 1996.

[6] P. Drucker, *Management Challenges for the 21st Century*. New York: Harper Business, 1999.

[7] Fielding, Whitehead, and Anderson, "Web Based Development of Complex Information Products," *Communications of the ACM*, vol. 41, pp. 84-92, 1998.

[8] M. Meyer and M. Zack, "The Design & Development of Information Products," *Sloan Management Review*, vol. 37, pp. 43-59, 1996.

[9] Robillard, "The Role of Knowledge in Software Development," *Communications of the ACM*, vol. 42, pp. 87-92, 1999.

[10] C. Shapiro and H. Varian, *Information Rules: A Strategic Guide to the Network Economy*. Boston, MA: Harvard Business School Press, 1999.

[11] M. Zack, "Electronic Publishing: A Product Architecture Perspective," *Information & Management*, vol. 31, pp. 75-86, 1996.

[12] H. Mendelson and K. Kraemer, "The Information Industries: Intorduction to the Special Issue," *Information Systems Research*, vol. 9, pp. 1-4, 1998.

[13] Zack, "An Architecture for Managing Explicated Knowledge," *Sloan Management review*, vol. Forthcoming, 1998.

[14] P. Drucker, *Post Capitalist Society*, First ed. New York, NY: Harper Business Press, 1993.

[15] W. Wong, *Management guide to software reuse*. Gaithersburg, MD: Nbs, 1988.

[16] K. P. Yglesias, "Information reuse parallels software reuse," *IBM Systems Journal*, vol. 32, pp. 615-620, 1993.

[17] A. Tiwana, *The Knowledge Management Toolkit: Practical Techniques for Building a Knowledge Management System*. Upper Saddle River, NJ: Prentice Hall, 2000.

[18] R. E. Bohn, "Measuring and Managing Technological Knowledge," *Sloan Management Review*, vol. 36, pp. 61-73, 1994.

[19] M. Bellander, "Workflow Bottlenecks and Problem Areas Influencing Production Management Need in Commercial Printing," presented at Intergrafica, Zagreb, Croatia, 1997.

[20] A. R. Jassawalla and H. C. Sashittal, "An examination of Collaboration in High Technology New Product Development Process," *Journal of Product Innovation Management*, pp. 237-254, 1998.

[21] A. W. Court, "The Relationship Between Information & Personal Knowledge in New Product Development," *International Journal of Information Management*, vol. 17, pp. 123-138, 1997.

[22] M. Iansiti and A. MacCormack, "Developing Products on Internet Time," *Harvard Business Review*, pp. 108-117, 1997.

[23] M. Song and M. Montoya-Weiss, "Critical Development Activities for Really New versus Incremental Products," *Journal of Product Innovation Management*, vol. 15, pp. 124-135, 1998.

[24] I. Nonaka and H. Takeuchi, *The knowledge-creating company: how Japanese companies create the dynamics of innovation*. New York: Oxford University Press, 1995.

[25] S. A. Faraj, *Coordinating expertise in software development teams*, 1998.

[26] M. Gunther, "Publish or Perish?," in *Fortune*, 2000, pp. 141-154.

[27] Techart, *Digital prepress book for Macintosh power user designers*, vol. 1-. Tokyo, Japan: TechArt Japan, 1993.

[28] L. Cottrell and A. Faulkner, *Print Publishing Guide*, First ed. San Francisco: Adobe Press, 1998.
[29] F. Katz, "Digital Age Challenges Acknowledged at Interactive Newspapers Conference," in *Atlanta Journal Constitution*. Atlanta, 1999.
[30] Ballou, Wang, Pazer, and Tayi, "Modelling Information Manufacturing systems to Determine Information Product Quality," *Management Science*, vol. 44, pp. 462-484, 1998.
[31] B. Reimers, "New Technologies Transform Publishing Industry," in *InformationWeek*, 2000, pp. 138-144.
[32] K. B. Clark and S. C. Wheelwright, *The product development challenge : competing through speed, quality, and creativity*. Boston: Harvard Business School Press, 1994.
[33] D. Leonard-Barton and S. Sensiper, "The Role of Tacit knowledge in Group Innovation," *California Management Review*, vol. 40, pp. 112-131, 1998.
[34] H. Varian, "Versioning Information Goods," presented at Digital Information and Intellectual Property, January 23-25, Cambridge, MA, 1997.
[35] A. Tiwana, "Managing Micro- and Macro-level Design Process Knowledge across Emergent Internet Information System Families," in *Industrial Knowledge Management --A Micro Level Approach*, R. Rajkumar, Ed. London: Springer U.K., 2000 (forthcoming).
[36] Mullins and Sutherland, "New Product Development in Rapidly changing Markets: An exploratory Study," *Journal of Product Innovation Management*, pp. 224-236, 1998.
[37] Malone, Yates, and Benjamin, "Electronic Markets and Electronic Hierarchies," *Communications of the ACM*, vol. 30, pp. 484-497, 1987.
[38] E. Y. Cross and M. B. White, *The diversity factor: capturing the competitive advantage of a changing workforce*. Chicago: Irwin Professional Pub., 1996.
[39] A. Webber, "What's So New about the Economy," *Harvard Business Review*, pp. 4-11, 1993.
[40] C. Ciborra, *Teams, markets, and systems: business innovation and information technology*. Cambridge [England] ; New York: Cambridge University Press, 1993.
[41] D. Mankin, S. Cohen, and T. Bikson, *Teams and Technology*, 1st ed. Boston, Massachusetts: Harvard Business School Press, 1996.
[42] D. Tjosvold and M. M. Tjosvold, *Leading the team organization: how to create an enduring competitive advantage*. New York 1991.
[43] C. S. O'Dell, APQC International Benchmarking Clearinghouse., and American Productivity & Quality Center., *Knowledge management : consortium benchmarking study : final report*. Houston, Tex. (123 N. Post Oak Lane, 3rd Floor, Houston 77024): American Productivity & Quality Center, 1996.
[44] T. H. Davenport and L. Prusak, *Working knowledge : how organizations manage what they know*. Boston: Harvard Business School Press, 1998.
[45] M. Webster, "Merriam Webster Dictionary on the Web http://www.m-w.com/cgi-bin/netdict,", vol. 1999, 1999.
[46] D. Teece, "Research Directions for Knowledge Management," *California Management Review*, vol. 40, pp. 289-292, 1998.

[47] B. Ramesh and V. Dhar, "Supporting Systems Development using Knowledge Captured during Requirements Engineering," *IEEE Transactions on Software Engineering*, 1992.

[48] P. M. Dillon, *The quest for knowledge management : a new service organization to address the challenges & opportunities*. [Atlanta, Ga.]: Information Management Forum, 1997.

[49] R. J. Dolan, *Managing the new product development process : cases and notes*. Reading, Mass.: Addison-Wesley, 1993.

[50] B. Ramesh and Tiwana. A., "*Supporting Collaborative Process Knowledge Management in New Product Development Teams*," *Decision Support Systems*, vol. 27, pp. 213-235, 1999.

[51] A. Inkpen, "Creating knowledge through collaboration," *California Management Review*, vol. 39, pp. 123-140, 1996.

[52] I. Nonaka, *Managing innovation self-renewing process*. J Bus Venturing 4 299-315 (1989), 1989.

[53] I. Nonaka and N. Konno, "The Concept of "Ba": Building a foundation for Knowledge Creation," *California Management Review*, vol. 40, pp. 40-55, 1998.

[54] Nonaka, Reinmoeller, and Senoo, "The ART of Knowledge: Systems to Capitalize on Market Knowledge," *European Management Journal*, vol. 16, pp. 673-684, 1998.

[55] J. G. March, *The pursuit of organizational intelligence*. Malden, Ma: Blackwell, 1999.

[56] R. E. Teigland, C. Fey, and J. Birkinshaw, "Knowledge Dissemination in Global R&D Operations: Case studies in three multinationals in the high technology electronics industry.," Stockholm School of Economics, Stolkholm 1998.

[57] R. Sanchez and A. Heene, *Strategic learning and knowledge management*. Chichester New York: Wiley, 1997.

[58] A. Chang and M. E. Jackson, *Managing resource sharing in the electronic age*. New York: AMS Press, 1996.

[59] L. Fahey and L. Prusak, "The eleven deadliest sins of knowledge management," *California Management Review*, vol. 40, pp. 265-276, 1998.

[60] N. Turek, "Publisher's Goal: Become a Powerful Portal Player," in *InformationWeek*, 2000, pp. 168-172.

[61] P. Kline and B. Saunders, *Ten steps to a learning organization*, 2nd ed. Arlington, Va.: Great Ocean Publishers, 1998.

[62] J. Boland, R. Tenkasi, and D. Te'eni, "Designing Information Technology to Support Distributed cognition," *Organization Science*, vol. 5, pp. 456-477, 1994.

[63] M. Klein, "Capturing Design Rationale in Concurrent Engineering Teams," *IEEE Computer*, pp. 39-47, 1993.

[64] E. Pena-Mora, D. Sriram, and R. Logcher, "SHARED-DRIMS: Shared Design Recommendation-Intent Management System," presented at Second Workshop on Enabling Technologies; Infrastructure for Collaborative Enterprises, Morgantown, WV.

[65] J. Conklin and M. Begeman, "gIBIS: A hypertext tool for exploratory policy discussion," *ACM Transactions on Office Information Systems*, vol. 6, pp. 303-331, 1988.

[66] H. A. Simon, "Bounded Rationality and Organizational Learning," *Organization Science*, vol. 2, pp. 125-134, 1991.

[67] M. Lease, M. Lively, and J. Leggett, "Using an Issue Based Hypermedia System to Capture the Software Life Cycle Process," *Hypermedia*, vol. 2, 1990.

[68] J. Lee, "Sybil: A Qualitative Decision Management System," in *Artificial Intelligence at MIT: Expanding Frontiers*, Whinston and Shellard, Eds. Cambridge, MA: MIT Press, 1990.

[69] H. Bhargava, R. Krishnan, and A. Whinston, "On Integrating Collaboration and Decision Technologies," *Journal of Organizational Computing*, vol. 3, pp. 297-317, 1994.

[70] S. Shum, "Negotiating the Construction of Organizational Memories," in *Negotiating the Construction of Organizational Memories*, U. Borghoff and R. Pareschi, Eds. New York: Springer, 1998.

[71] K. B. Yakemovic and E. J. Conklin, "Report on a Development Project Use of Issue Based Information System," presented at Computer Supported Cooperative work, 1990.

[72] B. Ramesh and K. Sengupta, "Multimedia in a Design Rationale Decision Support System," *Decision Support Systems*, vol. 15, pp. 181-196, 1995

[73] J. Mylopoulos, Telos: Representing Knowledge about Information Systems. ACM Transactions on Information Systems, 8 (1990)

[74] J. Allen and P. Hayes, Moments and Points in an Interval Based Temporal Logic. Computational Intelligence, 5 (Nov) (1989)..